SAVI DETERMINATION IN CARROTS: COMPARING CONSTANT AND DYNAMIC SOIL ADJUSTMENT FACTORS

J.L. Makries, and D.D. Warncke
Michigan State University, East Lansing, Michigan

Abstract

Reliable interpretation of reflectance measurements of vegetation in incomplete canopies is confounded by the influence of soil background. Qi et al. (2000) developed a fractional coverage (*f*c) model from the NDVI of target vegetation and soil. Spectral data from a two year (2001, 2002) carrot study was used to determine if the fractional coverage (*f*c) model could be used to estimate the observed fractional coverage of the developing carrot canopy. Reflectance measurements and matching digital images were taken throughout the growing season. The images were classified with Erdas Imagine software to quantify the amount of observed canopy coverage and validate the model. The *f*c model was best at estimating fractional coverage when the observed canopy was incomplete with R^2 as high as .91 ($P<.0001$). Once the carrot canopy attained full coverage the fc model did not compare as well to the observed coverage. N treatments had variable effect on the *f*c model.

Introduction

The sun angle, view angle and atmospheric conditions that alter remote sensing spectral signatures are increasingly corrected by improvements in atmospheric models but the canopy background "brightness" that affects the vegetation indices (VI) is not easily corrected and must be handled within the VI equation itself (Gao et al., 2000). The soil background has an impact because soil and vegetation spectral responses differ. The spectral response of soil generally rises gradually from the blue wavebands across the visible and near infrared (NIR) part of the spectrum. Spectral response of vegetation in the visible bands is punctuated with peaks and valleys as the reflectance measurements reveal signature absorption bands of chlorophyll pigments. In NIR vegetative responses rise above the spectral response of soil. When a pixel contains a mixture of soil and vegetation information, the spectral responses associated with differences in vegetative parameters such as crop development or in-season water and N management are diluted. In addition, the soil background is variable and sensitive to especially soil type, but also to wetting and drying cycles (Huete, 1987; Li et al., 2001). A major goal in remote sensing research of vegetation canopies is the separation of spectral changes due to vegetative response from those changes attributed to soil background; especially where studies involve spatial and temporal changes (Huete, 1987). Soil adjusted vegetation indices, developed for the purpose of correcting the background "brightness" have produced varying degrees of success depending on the canopy density. The purpose of this study is to compare the Soil Adjusted Vegetation Index (SAVI) using a constant soil adjustment factor ($L = 0.5$) with SAVI using a dynamic soil adjustment factor that changes as the canopy develops. The *f*c model, presented below, was used to calculate the changes in canopy development, and can be used to define L as (1-*f*c).

The Normalized Differential Vegetation Index (NDVI) first developed in 1979 by a NASA researcher, is a measure of the green, leafy vegetation density of vegetation (NASA, 2003). Ma et al. (2001) regarded NDVI as one of the best indices at predicting yield and midseason fertilizer amendments. NDVI utilizes the NIR and red wavebands in the following equation.

$$NDVI = (NIR - red)/(NIR + red) \quad [1]$$

Rondeaux et al. (1995) indicate NDVI is well related to vegetation amount until it saturates at full canopy coverage. It is advantageous in yielding biophysical relationships applicable across varying canopy types; values varied little between broadleaf crops and grasses. However, NDVI sensitivity to soil background affects these relationships and requires knowledge of the soil reflectance (Gao et al., 2000; Rondeaux et al., 1995). Most of its dynamic range occurs only with the presence of a soil background: the brighter the background the greater the dynamic range (Gao et al., 2000).

A number of soil adjusted vegetation indices have been developed, most of which are variations of the Soil Adjusted Vegetation Index (SAVI) developed by Huete (1988):

$$SAVI = (1 + L)*(NIR - R)/(NIR + R + L) \quad [2]$$

where L = a soil adjustment factor that diminishes as the vegetation grows denser. SAVI is more reliable and less noisy than NDVI. Rondeaux et al. (1995) found that SAVI has one of the lowest standard deviations when vegetation coverage is low and remains quite constant over the range of canopy coverage, improving further above 80% coverage. However, SAVI is less definitive between 50% and 80% canopy coverage than other indices in the study. The term (1+L) is used only to maintain the dynamic range of the index (Rondeaux et al., 1995) between -1.0 and 1.0. The term was eliminated from their final equation and the simplified version is:

$$SAVI = (NIR - R)/(NIR+R + L) \quad [3]$$

Although soil adjusted vegetation indices have considerably reduced the soil effects, determination of the vegetation characteristics still suffers from imprecision especially at relatively low canopy cover, if no information is known about the target (Rondeaux et al., 1995). L, as defined in Eqs. 2 and 3, diminishes as canopy density increases (Huete, 1988). Therefore, when measurements are taken throughout the growing season the definition of L should change as the canopy changes. However, L is typically assigned the value of 0.5. It is a reasonable approximation when the amount of soil in the scene is unknown (US Water Conservation Laboratory, 2003). A dynamic L would be more attractive if additional steps such as camera coverage or Leaf Area Index (LAI) measurements were not required to estimate the changing definition of coverage. The goal of this study was to eliminate additional steps by using the fractional vegetation coverage model to determination canopy coverage and substitute it for L as $(1-fc)$ in Eqs. 2 and 3.

Each pixel in an image normally contains a mixture of both soil and vegetation information, and the following model relates the relationship between the two physical characteristics (Qi et al., 2000):

$$S = f_c S_v + (1 - f_c) S_s \quad [4]$$

where fc = fractional green cover, 1- fc = fractional soil cover, Sv = vegetation reflectance, Ss = soil reflectance, and S = the remote sensing signal. In accordance with Qi et al.'s study, the NDVI was substituted for S in Equation 4 and algebraically rearranged to solve for fc:

$$fc = \left(NDVI_{any} - NDVI_{soil}\right)/\left(NDVI_{veg\,max} - NDVI_{soil}\right) \quad [5]$$

where vegetation maximum (veg max) indicates the highest vegetation NDVI from peak vegetation coverage. NDVI of the soil varies substantially with time and from location to location; therefore, soil NDVI is calculated from the reflectance of each image (Qi et al., 2000). Despite criticism of the effectiveness of NDVI, it is appropriate for use in this study according to Gao et al. (2000) because it is advantageous in defining biophysical relationships.

fc was used to determine fractional canopy coverage of the carrot canopy in the 2001 and 2002 field study using NDVI derived from reflectance measurements taken throughout the season and substituted for L in calculating SAVI, where L = (1-fc).

Materials and Methods

Experimental Sites, Plot Design, Management Protocol and Agronomic Sampling

Field studies were conducted at four locations during 2001 and 2002, in Montcalm County, Michigan. In both years plots were located at the Michigan State University Montcalm Experiment Station on moderately well drained loamy sand to sandy loam soil, of the Hillsdale-Spinks map unit (Hillsdale: coarse-loamy, mixed, mesic Typic Hapludalfs, Spinks: sandy, mixed, mesic Psammentic Hapludalfs) (D.L. Mokma, personal communication, 2003). In both years Diamond Cut and Goliath varieties were planted on flat beds in early May and harvested in mid-September. Each year plots were also established on commercial carrot fields, at Sandyland Farms, on Plainfield Sand, including a loamy substratum at the 2001 site, (mixed mesic Typic Udipsamments) (D.L. Mokma, personal communication, 2003). Asgrow B1 and Prime Cut 59 varieties were planted at the 2001 site, and Sugar Snax 54 was planted at the 2002 site. The fields were planted in mid-April on raised beds and harvested in mid-August. Barley was planted between rows to protect emerging plants and killed off once the carrots were established. Four replications of each of four N-treatments, 45, 90, 135, 180 kg ha^{-1} were arranged in a randomized complete block design at all locations. Weeds were controlled with linuron. Foliar blight was controlled with chlorothalonil.

Reflectance and Agronomic Measurements

Plant and soil reflectance measurements were made using a MSR87 multispectral radiometer (CropScan, Rochester, MN) equipped with the standard eight narrowband interference filters centered at 460, 510, 560, 610, 660, 710, 760, and 810 nm. Scanning direction was with the row, to minimize shadows by plants and the operator. The field of view was 28°, and measurements were viewed at nadir from a height of 2.55 m with a ground resolution diameter of 1.27 m. A digital camera was mounted alongside and at the same height as the radiometer. Images were taken of at least one scanned site per plot for a visual record of radiometric measurements. Ground resolution of the camera was 2.4 x 1.8 m. The images were used to determine percent vegetation coverage and verify the validity of the fc calculation as it related to carrot.

Image Processing

Digital images were cropped to match the area viewed by the radiometer with an image processing application (PhotoImpact 7, Ulead, Taipei, Taiwan). The supervised classification tools of Erdas Imagine 8.5 were used to redefine the pixels of the cropped image into soil and vegetation. This process made it possible to quantify the number of pixels attributed to soil and vegetation. The percent coverage was derived from the pixel count defined as vegetation.

The fc Calculation

fc was calculated according to Eq. 5. NDVI for each plot was calculated from the averaged NIR waveband, centered at 810 nm and red waveband, centered at 660 nm according to Eq. 1. In applying Eq. 5, $NDVI_{soil}$ for the Montcalm Experiment Station in 2001 was derived from the one set of soil reflectance measurements taken on May 18. Since the Sandyland location in 2001 was already established when plots were staked and a large enough area of bare soil was no longer available, the Experiment Station soil data was used in the model for Sandyland as an OVV, object void of vegetation. Soils from the two locations were similar in color, organic matter content, and water holding capacity. $NDVI_{soil}$ for both the Montcalm Experiment Station and the Sandyland location in 2002 was derived from on-site bare soil measurements taken throughout the season. $NDVI_{veg\ max}$ was derived from the seasonal peak canopy reflectance measurements obtained from each location. Regression analysis of relationships between the percent vegetation determined from the images and f_c calculated from Eq. 5 were evaluated using the multiple regression and general linear models (SAS Inst. Inc., Release 8.2/2003).

Results and Discussion

All data was normally distributed as evidenced by the Shapiro-Wilk test and residual plots. An outlier was defined as a viewing combination in which the camera and radiometer viewed different amounts of coverage as a result of gaps due to incomplete canopy coverage across the bed. Approximately 650 measurements were tested, and 12 were removed as outliers.

In 2001, reflectance measurements at the Experiment Station, began with plant emergence and showed that at about 45 days following emergence, the plant canopy was large enough to produce a usable comparison between the percent coverage derived from the classified digital images and the calculated fc, $R^2 = 0.54$ (p-value .0012). Measurements taken earlier resulted in coverage values so small that they were effectively zero. At days 51 and 54, fc according to Eq. 5, correlated with the amount of canopy coverage with $R^2 = 0.69$- 0.91 (p-values $<.0001$) at both locations (Table 1). As the canopy reached closure, correlation between the percent coverage derived from classified digital images and fc varied. At the experiment station, correlation between fc and percent vegetation coverage derived from the digital images appeared to diminish at about 86 days of development. Canopy coverage ranged from 87 to 96% according to the classified digital images. But at Sandyland correlation of fc lasted until the carrot crop was 91 days old, at which time canopy closure was at 99%. The successful Sandyland results also indicated that the experiment station soil reflectance could be used as an object void of vegetation (OVV) in the Sandyland data for the sole purpose of calculating fc.

During the 2002 season (Table 2) reflectance measurements were delayed until later in the season and continued beyond peak canopy closure until harvest, since early measurements in

2001 resulted in effectively zero coverage values. Most of the measurements were taken during the last 45 days before harvest, over canopies at 90-99% closure, according to the classified digital images, and also revealed that once the canopy reached peak closure, the correlation with fc diminished.

Table 1. 2001 Regression analysis of Percent Vegetation Coverage (PVC) vs Calculated fc (PVC = a + bfc + cTreatment) where a is the intercept, and b and c are regression coefficients. Treatment did not significantly influence correlation of PVC and fc at p = 0.05.

Date	DAP†	y Intercept	fc Coefficient (b)	R^2	p-value
		Montcalm Experiment Station			
5/18/01	10	0	0	0	0
6/13/01	36	0	0	0	0
6/22/01	45	-0.0194	0.9657	0.54	.0012
6/28/01	51	-0.0157	1.1561	0.78	<.0001
7/5/01	58	-0.0897	1.2464	0.89	<.0001
7/12/01	65	-0.0751	1.0856	0.73	<.0001
7/20/01	73	-0.1038	1.0933	0.91	<.0001
8/2/01	86	0.0945	0.8903	0.60	.0004
8/9/01	93	-0.0565	1.0518	0.68	<.0001
8/17/01	101	-1.1406	2.1257	0.39	.0091
		Sandyland (Deaner Rd)			
6/13/01	54	0.0671	0.8485	0.75	<.0001
6/22/01	63	0.0427	0.7893	0.69	<.0001
6/28/01	69	-0.0643	1.0200	0.88	<.0001
7/5/01	76	-0.3450	1.3534	0.88	<.0001
7/12/01	83	-1.0679	2.1098	0.78	<.0001
7/20/01	91	-1.2507	2.2358	0.78	<.0001
8/9/01	111	0	0	0	0
8/17/01	119	0.9041	0.0902	0.04	.4500

†Days after planting.

It was especially notable in the Goliath data. On July 17, and 24, fc correlated with percent vegetation coverage at R^2 = .80 and .82 (p-value <.0001) but dropped sharply, thereafter. The 2002 Sandyland location experienced a number of equipment mishaps which interrupted collection of data. Of the three dates shown in Table 2, August 9, and 15, were at full canopy coverage and also exhibited the same late season lack of correlation between the digital image coverage and fc.

A full canopy whether defined by fc or percent vegetation coverage derived from classified digital images is equal to 1.0, with the regression analysis resulting in zero or at least very low correlation due to clustering of points. Tables 1 and 2 indicate a late season drop in correlation at all four locations; however, the time at which the clustering appeared varied. Population and varietal differences such as leaf orientation, leaf size and canopy fullness, and developmental rate can contribute to timing of full canopy. Differences between late season results may have been affected, in part, by the manner in which the digital images were classified.

Table 2. 2002 Regression analysis of Percent Vegetation Coverage (PVC) vs Calculated fc (PVC = a + bfc + cTreatment) where a is the intercept, and b and c are regression coefficients. Treatment significantly influenced correlation of PVC and fc on the dates indicated at p = 0.05.

Date	DAP†	y Intercept	fc Coefficient (b)	Trt Coefficient (c)	R^2	p-value
		Montcalm Experiment Station/Diamond Cut				
5/21/02	14	0	0	0	0	0
7/17/02	71	0.2325	0.7450	-0.0006	0.66	.0008
7/24/02	78	0.3467	0.6432	ns	0.45	.0040
8/1/02	86	0.8221	0.1634	-0.0043*	0.39	.0400
8/9/02	94	0.6757	0.2852	ns	0.27	.0400
8/15/02	100	0.7867	0.2119	-0.0001	0.70	.0014
8/21/02	106	0.3912	0.6151	-0.0001	0.54	.0066
8/30/02	115	0.4771	0.4281	ns	.11	.2100
9/6/02	122	0.0732	0.9615	-0.0002	.74	.0003
		Montcalm Experiment Station/Goliath				
5/21/02	14	0	0	0	0	0
7/17/02	71	-0.1192	1.1238	ns	0.80	<.0001
7/24/02	78	0.0242	0.9565	ns	0.82	<.0001
8/1/02	86	0.5801	0.4052	ns	0.62	.0003
8/9/02	94	0.5372	0.4161	ns	0.40	.0089
8/15/02	100	0.4414	0.5360	ns	0.44	.0048
8/21/02	106	-0.3951	1.4147	-0.0003	.64	.0010
8/30/02	115	0.7422	0.1372	ns	.005	.8000
9/6/02	122	0.9102	-0.0098	ns	.0001	.9680
		Sandyland (Masters Rd)				
7/24/02	89	0.3606	0.5869	ns	0.30	.0300
8/9/02	105	0.3016	0.6766	ns	0.22	.0700
8/15/02	111	0.9214	0.0695	ns	0.04	.4700

p-value 0.08
† Days after planting

Shadows, which represented either small pockets of soil or shaded leaves nestled in the canopy, were difficult to distinguish in the images. The shadows, which represented a decrease in light spectra, also affected the resulting reflectance measurements. Incorrect interpretation of the shadows in the digital images could have affected manifestation of the actual correlation of the images versus fc.

In 2002, the Goliath variety, at the Experiment Station, was affected by foliar blights. The canopy coverage was reduced during the latter part of the season and it was expected that the percent coverage derived from classified digital images versus fc would return to a more linear relationship; however, that was not the result and the clustering of points persisted (Table 2). The difficulty of interpreting leaf discoloration as it appeared in the images in relation to the reflectance measurements may have been the cause.

Treatment differences in carrot related to nitrogen rates using remote sensing were inconclusive. Nitrogen treatment did not significantly influence the prediction of canopy coverage in 2001. There were significant pairwise differences, however not sequentially. Significant exceptions were noted in Table 2 where on several occasions treatment was a significant factor in the prediction of percent canopy coverage

Since the amount of nitrogen applied, as well as other factors, influences the appearance of the canopy and therefore, the amount of fractional coverage (fc) multicollinearity relationships could exist between the independent variables, fc and treatment. The independent variables were compared using regression analysis and the variance inflation factor (VIF) for those dates on which treatment did not appear significant. Relationships were significant at p-value 0.05 on five occasions. However, VIF results ranged from 1.4 to 6.3 eliminating multicollinearity as a significant factor for treatment non-significance (Ott and Longnecker, 2001).

Overall, fc correlated with percent vegetative coverage reasonably well throughout most of the season. Earliest correlation was possible at about 45 days at the experiment station, 2001. Other varieties may vary according to growth patterns and climate. Saturation of fc occurred at peak canopy coverage when $fc = 1.0$. L, the soil adjustment factor of SAVI, is defined as zero at full coverage and therefore $(1-fc)$ satisfies the soil adjustment factor at saturation.

SAVI was derived for all reflectance measurements according to Eq. 3 using fc as the soil adjustment factor $L = (1-fc)$ to determine whether it improved accuracy of the vegetation index. As the comparison, L was held constant at 0.5 according to Huete (1988) and adopted by Rondeaux et al. (1995) and Gao et al. (2000) as a basis for their comparative model testing. The multiplier (1+L) was eliminated in both versions of SAVI as Rondeaux et al. (1995) had done.
The resulting curves plotted over time, were within the expected range (-1.0 to 1.0) for SAVI and resembled the growth curve. Without the multiplier, SAVI, where $L = (1-fc)$, did not plateau at peak canopy and the treatment effect remained separated. Fig.1 is an example of the SAVIfc with and without the multiplier $(1+(1-fc))$. The data from the other locations exhibited similar differences. Without the multiplier (1+L), the $L = (1-fc)$ substitution in SAVI (SAVIfc) did not measurably change the outcome of SAVI in the carrot crop. In fact, regression analysis comparing SAVI with SAVIfc (Table 3) revealed a significant relationship at $R^2 = 0.99$ to 1.0 for every date throughout the season at all four locations.

SAVI was also derived for all reflectance measurements according to Eq. 2, which includes the multiplier (1+L). Where L was held constant at 0.5, treatment differences remained separated and resembled the growth curve; however, the index exceeded its expected range when canopy coverage was dense. However, when $L = (1-fc)$ was substituted, SAVI was held to its dynamic range of -1.0 to 1.0, but the curves plateaued at peak canopy coverage and treatment differences were no longer distinguishable. Fig. 2, depicts the comparison between $L = 0.5$ and $L = (1-fc)$.

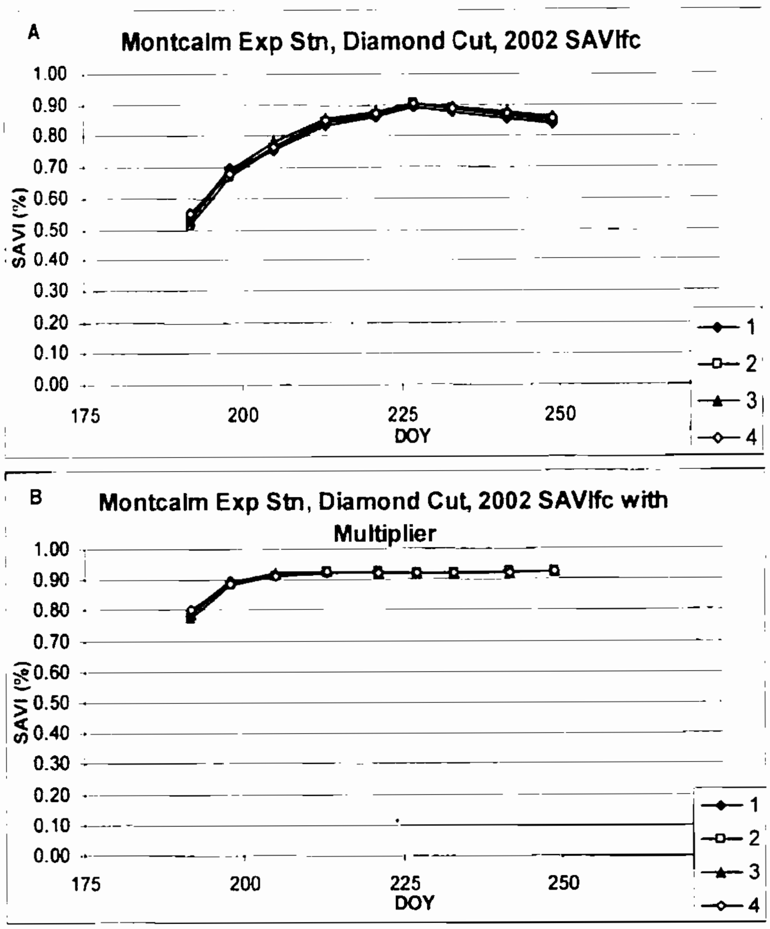

Fig. 1 Example of the difference between SAVIfc with and without the (1+L) multiplier. The Exp Stn 2002, Diamond Cut data is shown here, the other locations exhibited similar differences.

Differences between SAVI and SAVIfc were expected to occur during early and late developmental stages of the carrot crop when the canopy coverage, and therefore fc, differed from the previously defined L = 0.5. The magnitude of the differences between L = 0.5 and L = (1-fc) as applied to Eq. 3 was not great enough to change the outcome and the two versions have the same results. When Eq. 2 was applied, Fig. 2 showed SAVIfc preserved the dynamic range of SAVI even in dense canopy coverage, while L held constant at 0.5 exceeded the expected range by as much as 30%. Fig. 2 also showed that the curves cross each other at the point where L = .5 under either definition of L as expected, approximately 63 to 65 days after planting (Table 3) at about 50% canopy coverage. Where L was held constant, SAVI, while a reasonable estimation (US Water Conservation Laboratory), was understated in low canopy coverage and overstated in dense canopy conditions compared to SAVIfc.

Conclusion

We used images to assess the reliability of fc in estimating canopy coverage and found that as the canopy neared closure fc tended to saturate. Late season images presented challenges in interpretation of the shadows created by the sun angle reflecting off soil and shaded leaves and leaf discoloration. However, we found that fc could be used to estimate percent vegetation

Table 3. Results of regression analysis of SAVI comparing L = 0.5 and L = (1-fc) according to Eq. 3.

Date	Days†	Average 1-fc‡	R^2	Date	Days†	Average 1-fc‡	R^2
Montcalm Exp Stn				Sandyland (Deaner Rd)			
5/18/01	10	1.00	1.00***				
6/13/01	36	1.00	1.00***	6/13/01	54	0.84	1.00***
6/22/01	45	0.91	1.00***	6/22/01	63	0.51	1.00***
6/28/01	51	0.89	1.00***	6/28/01	69	0.31	1.00***
7/5/01	58	0.77	1.00***	7/5/01	76	0.19	1.00***
7/12/01	65	0.61	1.00***	7/12/01	83	0.07	0.99***
7/20/01	73	0.32	1.00***	7/20/01	91	0.02	0.99***
7/26/01	79	0.15	1.00***	7/26/01	97	0.02	0.99***
8/2/01	86	0.05	0.99***	8/2/01	104	0.01	0.99***
8/9/01	93	0.03	0.99***	8/09/01	111	0.02	0.99***
8/17/01	101	0.01	0.99***	8/17/01	119	0.02	0.99***
9/6/01	121	0.05	0.99***				
Montcalm Exp Stn. Diamond Cut				Montcalm Exp Stn. Goliath			
5/21/02	14	1.00	1.00***	5/21/02	14	1.00	1.00***
7/11/02	65	0.49	1.00***	7/11/02	65	0.54	1.00***
7/17/02	71	0.31	1.00***	7/17/02	71	0.31	1.00***
7/24/02	78	0.20	0.99***	7/24/02	78	0.18	1.00***
8/1/02	86	0.09	0.99***	8/1/02	86	0.07	0.99***
8/9/02	94	0.06	0.99***	8/9/02	94	0.05	0.99***
8/15/02	100	0.02	0.99***	8/15/02	100	0.02	0.99***
8/21/02	106	0.04	0.99***	8/21/02	106	0.03	0.99***
8/30/02	115	0.07	0.99***	8/30/02	115	0.06	0.99***
9/6/02	122	0.09	0.99***	9/6/02	122	0.09	0.99***
Sandyland (Masters Rd)							
7/11/02	71	0.09	0.99***				
7/17/02	82	0.05	0.99***				
7/24/02	89	0.04	0.99***				
8/1/02	97	0.03	0.99***				
8/9/02	105	0.03	0.99***				
8/15/02	111	0.02	0.99***				

† Days means number of days since planting.
‡ All treatments were combined to show general coverage at the specified days after planting.
*** p-value <.0001

coverage. When fc was used as the soil adjustment factor, L = (1-fc) to calculate SAVI according to Eq. 2, it was determined that for the carrot study 2001 and 2002, L = (1-fc) held SAVI to its dynamic range of -1.0 to 1.0 even when the canopy was dense; however, differences between treatments were best viewed when SAVIfc was determined according to Eq. 3.

The choice of L in SAVI type indices is critical in minimizing the soil background effect (Rondeaux et al., 1995) and should also be simple to apply especially if these indices will ever become part of production agriculture. fc is easy to apply as the definition of the soil background adjustment factor because it is obtained from reflectance measurements which would already be available.

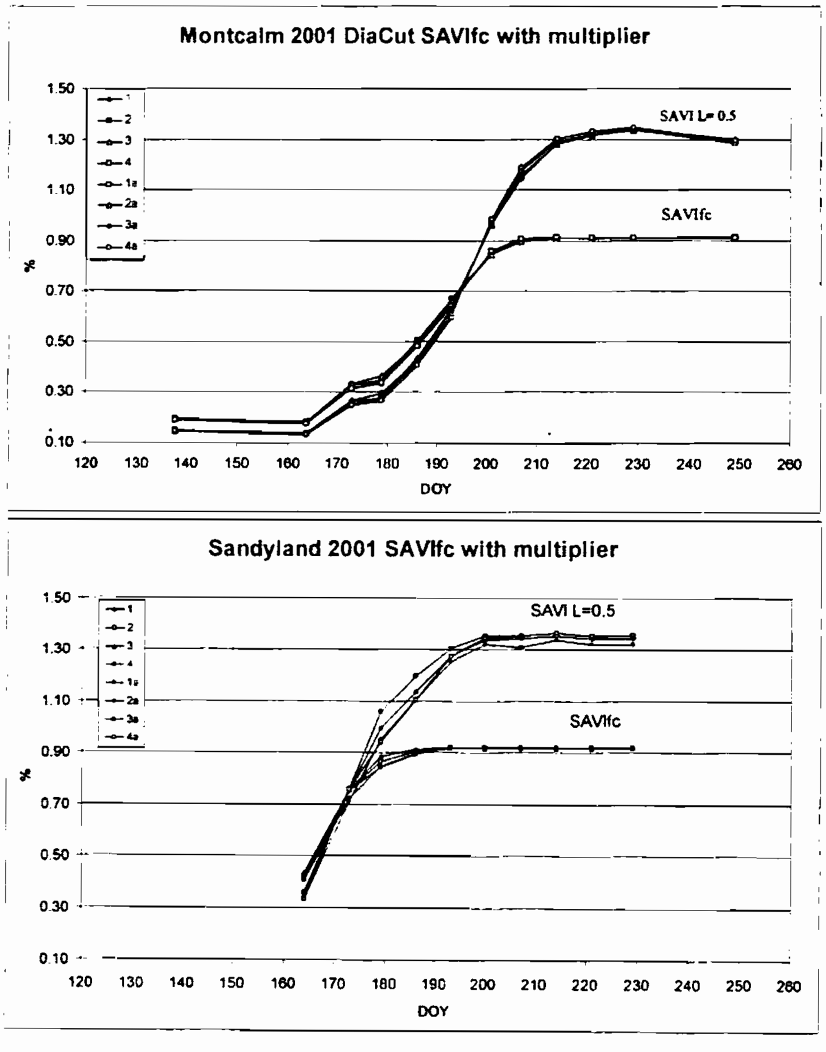

Fig. 2 2001. Comparison of SAVI L = 0.5 (1a, 2a, 3a, 4a), and SAVI L = (1-fc) (1, 2, 3, 4) according to Eq. 2.

References

Gao, X., A.L. Huete, W. Ni. and T. Miura. 2000. Optical- biophysical relationships of vegetation spectra without background contamination. Remote Sens. Environ. 74:609-620.

Huete, A. R. 1987. Soil-dependent spectral response in a developing plant canopy. Agron. J. 79:61-68.

Huete, A.R. 1988. A soil-adjusted vegetation index (SAVI). Remote Sens. Environ. 25:295-309.

Ma, B.L., L.M. Dwyer, C. Costa, E.R. Cober, and M.J. Morrison. 2001. Early prediction of soybean yield from canopy reflectance measurements. Agron. J. 93:1227-1234.

NASA. 2003. Earth observatory: How plants can change our climate [Online]. Available at http://earthobservatory.nasa.gov/Study/LAI/LAI2.html (verified 17 Sept. 2003)

Ott, R.L., and M. Longnecker. 2001. An introduction to statistical methods and data analysis. 5th ed. Duxbury, Pacific Grove, CA.

Qi, J., R.C. Marsett, M.S. Moran, D.C. Goodrich, P. Heilman, Y.H. Kerr, G.Dedieu, A. Chehbouni, and X.X. Zhang. 2000. Spatial and temporal dynamics of vegetation in the San Pedro river basin area. Agric. For. Meteorol. 105:55-68.

Rondeaux, G., M. Steven, and F. Barret. 1995. Optimization of soil-adjusted vegetation indices. Remote Sens. Environ. 55:95-107.

US Water Conservation Laboratory. 2003. How a vegetation index works [Online]. Available at http://www.uswcl.ars.ag.gov/epd/remsen/Vi/VIworks.htm (verified 7 Oct. 2003)

PROCEEDINGS OF THE

THIRTY-THIRD NORTH CENTRAL EXTENSION-INDUSTRY SOIL FERTILITY CONFERENCE

Volume 19

November 19-20, 2003
Holiday Inn University Park
Des Moines, IA

Program Chair:
John E. Sawyer
Iowa State University
Ames, IA 50011
(515) 294-1923

Published by:
Potash & Phosphate Institute
772 – 22nd Avenue South
Brookings, SD 57006
(605) 692-6280
Web page: www.ppi-ppic.org